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SEQUESTRATION OF CARBON OXIDE IN DIFFERENT FERTILIZATION SYSTEMS IN AGROCENOSES

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Aim. To substantiate the agroecological estimation of the performance of a short crop rotation in conditions of intense and organic system of fertilization on the basis of restoring normative parameters of emission and sequestration of C-CO_2 circulation while using by-products as organic fertilizers in conditions of modern climatic system of the Forest-Steppe of Ukraine. **Methods.** Field, statistical, laboratory. **Results of Investigations.** The performance of short crop rotations is determined by the capacity of C-CO_2 balance. Strong inverse correlation was found between the capacity of N and the ratio between C and N in the agrocenosis, which demonstrated that enhancing the humification processes (ratio constriction) led to the increase in the capacity of C_{org} balance and the decrease in the capacity level of C-CO_2 balance (enhancing mineralization), related to the reduction in the performance of crops in the agrocenosis of a crop rotation compared to the organic system of fertilization. The capacity of C-CO_2 and C_{org} balance correlates at the medium level of inverse direction, and the yield of the main products, feed units and digestible protein correlates at the level of strong direct correlation. **Conclusions.** General mineralization of by-products and humus in the agrocenosis and humification processes are antagonists, so extending the ratio between C and N at the intense fertilization system stimulates the increase in performance and reducing C to N similar to the organic fertilization system enhances the humification process due to binding of C_{org} into humus and limits mineralization which leads to the reduction in agrocenosis performance at the organic fertilization system.

Keywords: sequestration, carbon monoxide, organic fertilizer system, balance capacity, basic products, digestible protein.

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INTRODUCTION

The issue of organic carbon transformation in soil, its dynamics, functions and regulating the flows in the agrocenosis system using mineral and organic fertilizers are promising trends of agrosoil study as fundamental science. The increase in supplies of carbon, accessible for microorganisms, may be an efficient way of optimizing the nitrogen regime of soil due to the support of balanced carbon-nitrogen interactions. The accumulation of CO_2 concentration in the surface layer of the atmosphere is accompanied with the increase in pure photosynthetic assimilation of carbon, thus promoting the increase in pure initial production of agricultural crops due to the "fertilizing effect of CO_2" [1–3]. Enhancing the performance of plants in conditions of increased CO_2 concentrations envisages the increase in the length of roots, the share of thin roots due to a higher need for soil moisture and nutrients and the mass of plant residues in general [4]. In case of global increase in CO_2 concentration in the atmosphere by 100 ppm, the performance of plants may be enhanced by 8.0–25.0 % [5]. Due to the increase in the atmospheric concentration of CO_2, there are expectations not only for the increase in nitrogen removal with the harvest by 5.0–33.0 %, but also a considerable change in the character of soil nitrogen dynamics via the decrease in nitrogen concentration in plant biomass and the increase in the share of organic substances in plant residues, resistant to decomposition [6].

The aridization of climate leads to the decrease in C-CO_2 depositing in ecosystems and agroecosystems which is related to the increase in the intensity of destructive processes: the rate of organic matter mineralization in soil is enhancing, soil breathing is activated which, in case of excessive manifestation, leads to exceeding the rate of atmospheric CO_2 accumulation by plants, and eco- and agroecosystems transform into active sources of emission of carbon dioxide into the atmosphere [7–9].

Ensuring soil sequestration of carbon in the agrocenosis becomes an urgent nature-oriented task of agrosoil study. Carbon-sequestrating practice of agriculture envisages the increase in organic carbon content in soil due to the increase in the mass, which returns to the soil. A key role in these technologies is given to the application of a fertilization system, promoting the stimulation of a producing process, increasing the mass of by-products at both intense and organic system of fertilization.

Aim. To substantiate the agroecological estimation of the performance of a short crop rotation in conditions of intense and organic systems of fertilization on the basis of restoring normative parameters of emission and sequestration of C-CO_2 circulation while using by-products as organic fertilizers in conditions of modern climatic system of the Forest-Steppe of Ukraine.

METHODS OF STUDIES

The studies were conducted in the field permanent experiment of the Cherkasy State Agricultural Experimental Station of the National Scientific Center "Institute of Agriculture", NAAS of Ukraine, established in 2010. The soil was regraded low-humus medium-clay chernozem on carbonate forest layer. The content of humus in the 0–30 cm layer was 2.76–3.03 % according to Turin, the amount of absorbed alkali – 24.5–28.1 mg-eq. per 100 g of soil, the hydrolytic acidity – 1.99–2.19 mg-eq./100 g of soil, pH of the salt extract – 5.5–6.3. The degree of saturation with alkali was 92.8–93.3 %, the content of mobile forms of phosphorus (according to Truog) – 9.0 mg per 100 g of soil, exchange potassium (according to Brovkina) – 12 mg per 100 g of soil. The physical features of soil were characterized by the indices: relative weight of solid phase – 2.57–2.62 g/cc, structure density – 1.24–1.30 g/cc, total cleavability of humus horizon – 50–53 %.

The studies were conducted in the five-field grain-growing and weeding crop rotation as follows: peas – winter wheat – corn – soy – spring barley. The saturation of the presented crop rotation with legumes was over 30 %. The organic system of fertilization: without the introduction of mineral fertilizers and the use of by-products of the predecessor as a fertilizer (14 t/ha), after treating grain with nitrogen-fixing, phosphorus-mobilizing biological preparations, growth regulators, humates and enriching with humates, growth regulators for plants or a biopreparation. The intense system of fertilization: pea – $N_{30}P_{30}K_{30}$, winter wheat – $N_{60}P_{60}K_{60} + N_{30}$, soy – $N_{60}P_{60}K_{60}$, corn – $N_{60}P_{70}K_{60} + N_{20}$, spring barley – $N_{60}P_{60}K_{60} + N_{25}$ at the introduction of 15 t/ha of by-products as an organic fertilizer. The method of processing in crop rotations was differentiated. The yield of phytomass structure was determined according to [11], the reserves of nitrogen in the phytomass structure were defined by calculations [12–13]. The generalization of materials and estimation of the study results was conducted by the method of disperse analysis [14] and using STATISTICA package using the non-parametric method.

The estimation of the accumulation of carbon monoxide amount while cultivating grain crops was performed on the following basis:

- crop capacity in different crop rotations in 2000–2015;
- yield of by-products, after-harvest residues and roots of crops in crop rotations according to the regression equations, presented for low and high levels of crop capacity, as the dependence of the number of plant residues is not always in direct relation to the harvest increase;
- estimation of the yield of dry matter from the obtained mass;
- estimation of carbon content in the mass of by-products, stubble and roots calculated into carbon oxide (coefficient 3.7);
- estimation of the amount of humus, which was formed as a reservoir of carbon depending on the level of the input of straw, by-products and mass of root system of plants into soil.

RESULTS OF INVESTIGATIONS

The technologies of cultivating agricultural crops which are based on fertilization systems, different by their intensity, play a relevant role in transforming carbon dioxide of the atmosphere into plant biomass, which mostly consists of organic carbon. Noteworthy is the ratio of involved C-CO_2 of the atmosphere in the structure of total phytomass of the harvest, released during the mineralization of humus and by-products which will impact both C-CO_2 balance and its intensity, and the capacity of CO_2 balance in the agrocenosis of a short crop rotation.

The average involvement of C-CO_2 in the formation of the main products was 7.27 t/ha at the amplitude range from 5.80 t/ha to 8.11 t/ha (+2.31 t/ha). By the median, the involvement of C-CO_2 in the main products was 7.41 t/ha and leaned towards the upper typical value (8.11 t/ha), and the typed variation of the involvement of C-CO_2 was 1.58 t/ha. The variation coefficient was at the level of 11.5 % and the asymmetry coefficient was negative and deviated considerably from the center of sampling distribution (Table 1).

While using the organic system of fertilization, the average involvement of C-CO_2 in the main products decreased 1.22 times and by the median – 1.25 times. The amplitude range of involving C-CO_2 was shifted towards smaller absolute interval values, and the range itself was decreased 1.10 times. The involvement of C-CO_2 in the main products mostly leaned towards the upper typical interval value (6.62 t/ha). The coefficient of the variation in involving C-CO_2 was 11.5 %, and the coefficients of asymmetry and excess had positive values and insignificant deviation from the distribution center. At the intense fertilization system, the involvement of C-CO_2 in by-products was 21.8 t/ha both by the average value and the value by the median. The amplitude range was 1.95 times wider than the normalized range, and the value for the involvement of C-CO_2 mostly leaned towards the upper typical value.

Table 1. Statistical parameters of C-CO_2 balance of a short crop rotation depending on the fertilization systems in 2010–2017

Statistical parameters	*Yield of f.u., t/ha	Yield of digestible protein, t/ha	Weight, t/ha: main products –	of above-ground mass	of roots	non-market products –	of total phytomass
The intense system of fertilization							
Parameter, t/ha							
Average (X)	6.49	0.59	5.04	15.0	11.8	27.6	31.4
min	5.10	0.46	4.00	12.9	9.36	22.3	26.3
max	7.31	0.68	5.61	16.0	12.6	32.5	34.2
Quantiles of parameter							
Med, P 0.50	6.64	0.61	5.12	15.2	12.2	28.0	32.0
L 0.25	6.00	0.52	4.60	14.4	12.0	26.4	29.5
L 0.75	7.21	0.64	5.54	16.0	12.4	28.6	33.7
Coef. V, % – variation coefficient	11.8	12.9	11.4	7.23	9.41	11.0	8.93
0.46 Coef. V, % – approximation error	5.43	5.93	5.24	3.33	4.33	4.73	4.11
The organic system of fertilization							
Parameter, t/ha							
Average (X)	5.33	0.50	4.12	13.6	11.5	25.1	29.2
min	4.41	0.39	3.44	12.8	10.9	23.7	27.1
max	6.31	0.64	4.86	15.3	12.0	27.3	32.2
Quantiles of parameter							
Med, P 0.50	5.21	0.48	4.01	13.2	11.4	24.6	28.6
L 0.25	5.01	0.47	3.86	13.0	11.4	24.4	28.3
L 0.75	6.01	0.56	4.61	14.4	11.8	26.2	30.8
Coef. V, % – variation coefficient	12.1	15.7	11.7	6.78	3.06	4.95	5.92
0.46 Coef. V, % – approximation error	5.57	7.22	5.38	3.12	1.41	2.28	2.72

Note: Δ=max-min – amplitude range; $\Delta L = L_{0.75} - L_{0.25}$ – normalized typical range; * f.u. – feed units (t/ha).

At the organic fertilization system, the value of involving C-CO_2 to by-products by the average and median values coincided and was 1.11–1.15 times lower compared to the intense system of fertilization. The amplitude (Δ) and normalized typical range (ΔL) of C-CO_2 to by-products was lower by the absolute value with the highest difference by the minimal typical value ($L_{0,25}$) which was at the level of 18.6 t/ha against 20.8 t/ha and 20.8 t/ha against 23.0 t/ha by the upper typical value ($L_{0,25}$) regarding the control fertilization system. The variation coefficient (Coef. V, %) was at the level of 5.8 %, and the asymmetry coefficient (Ka) had a positive value with insignificant deviation from the center of parameter sampling.

The involvement of C-CO_2 in the formation of the root system at the intense fertilization system by the average (X) and median values coincided (17.4–7.6 t/ha). The amplitude range and interval typical value were equal. The variation coefficient was at the level of 1.62 % and the asymmetry coefficient was positive and deviated inconsiderably from the center of parameter distribution. A similar estimation was notable for the involvement of C-CO_2 in the root system at the low-cost fertilization system, the difference being that Coef. V. = 3.17 %, and the asymmetry coefficient had a negative value with insignificant deviation from the center of distribution of parameter sampling.

Table 2. Statistical parameters of CO_2 balance of a short crop rotation depending on the fertilization systems in 2010–2017

Statistical parameters	Involved CO2 in the formation (t/ha):				Released CO2 from (t/ha):			Balance of CO_2, t/ha (B-CO_2)	Intensity of balance, % Ib-CO_2	Capacity of CO_2 balance, t/ha (Cap.bC-CO_2)
	main products	by-products	roots	total of phytomass	minerali-zation of by-products	mineralization of humus	total			
The intense system of fertilization:										
Parameter, t/ha										
Average (X)	7.27	21.8	17.6	46.0	34.9	12.2	46.7	0.46	101	93.0
min	5.80	19.9	17.4	40.0	31.0	9.6	45.0	–1.60	96.5	86.0
max	8.11	23.3	18.0	49.1	37.0	17.1	49.0	6.00	115	98.0
Quantiles of parameter										
Med, P 0.50	7.41	21.8	17.4	46.6	35.5	12.1	46.0	0.00	99.0	92.0
L 0.25	6.61	20.8	17.4	45.6	34.0	10.6	45.0	–1.00	98.0	90.0
L 0.75	8.11	23.0	18.0	49.1	36.0	12.2	48.0	0.30	101	97.0
Coef. V, % – variation coefficient	11.5	5.91	1.62	6.72	5.57	19.6	3.43	554	6.18	4.61
0.46 Coef. V, % – approximation error	5.29	2.53	0.75	3.05	2.56	9.01	1.58	254	2.84	2.12
The organic system of fertilization:										
Parameter, t/ha										
Average (X)	5.97	19.6	16.6	42.3	32.7	10.4	43.2	0.75	103	85.3
min	4.91	18.4	15.7	39.0	30.8	9.30	40.1	–1.00	101	79.0
max	7.01	21.4	17.3	46.0	35.4	11.1	46.5	1.51	104	93.0
Quantiles of parameter										
Med, P 0.50	5.91	19.1	16.6	41.9	32.5	10.4	43.0	1.11	103	85.0
L 0.25	5.51	18.6	16.4	40.5	31.7	10.2	42.0	0.21	101	83.0
L 0.75	6.62	20.8	17.0	44.6	34.0	10.9	44.8	1.51	104	89.0
Coef. V, % – variation coefficient	11.5	5.81	3.06	5.74	4.68	5.43	4.75	124	1.22	5.32
0.46 Coef. V, % – approximation error	5.29	2.67	1.41	2.64	2.15	2.51	2.19	57.0	0.56	2.45

Note: Δ=max-min – amplitude range; ΔL= $L_{0.75}$ – $L_{0.25}$ – normalized typical range.

In conditions of the organic system of fertilization, the involvement of C-CO_2 in the root system decreased 1.06 times and reached 16.6 t/ha. The amplitude range increased 2.67 times and its values shifted to absolutely lower values (15.7–17.3 t/ha). The values of median (Med, $P_{0.50}$) coincided with average values, and the typed interval values of involving C-CO_2 in the root mass were 1.05–1.06 times lower.

The coefficient of variation for the mentioned parameter did not reach 5 % and the asymmetry coefficient had a negative value with insignificant deviation from the center of sampling.

46.0–46.6 t/ha C-CO_2 was involved in the total phytomass in conditions of intensive system of fertilization by the average value and the median. The amplitude range was 2.6 times wider than the normalized typical range and the value of involving C-CO_2 by median leaned towards the lower typical value (45.6 t/ha). The variation coefficient did not exceed 7 %, and the coefficients of asymmetry and excess had a considerable deviation from the center of distribution, but they had opposite values.

At the organic fertilization system, the binding of C-CO_2 in the total phytomass by the average and median values was 1.09 and 1.11 times lower compared to the control variant of fertilization, and the median mostly leaned towards the lower typical value (40.5 t/ha) that was 1.13 times lower which impacted the normalized range of the parameter that was 1.17 times higher compared to the control fertilization system. The variation coefficient of the parameter did not exceed 6 %, and the coefficients of asymmetry and excess, although of opposite signs, did not deviate considerably from the center of distribution, which demonstrated the moderate nature of involving C-CO_2 in the formation of the total phytomass in the agrocenosis of the short crop rotation at the organic fertilization system. At the intense fertilization system, the involvement of C-CO_2 for the formation of structural components (main products – B, by-products – C, root system – D) occurred by the ratio of B : C : D=1 : 2.95 : 2.36, and by the percentage content: B – 15.9 %, C – 46.8 %, D – 37.3 %. At the organic system of fertilization: B : C : D=1 : 3.23 : 2.80 and 14.1 %, 45.6 %, 40.3 % in accordance to the phytomass components.

While transferring from the intense system of fertilization to the organic system, 1.1 and 1.2 times more C-CO_2 was involved per one unit of involving C-CO_2 in the main products for the formation of by-products and the root mass compared to the intense system of fertilization, which reflected on the percentage structure of the total biomass: there was a re-distribution of the structure for the benefit of by-products and roots.

At the intense fertilization system (Table 2) the intensity of mineralization of the by-products or the emission of C-CO_2 was 34.9 t/ha at the amplitude range from 31.0 t/ha to 37.0 t/ha. The emission of C-CO_2 by the median mostly leaned towards the upper typical value (36 t/ha), and the typed range of the emission of C-CO_2 was 3 times more constricted compared to the amplitude range. The coefficient of variation for the mentioned parameter exceeded 5 %, and the coefficient of asymmetry had a considerable deviation from the center of distribution and a negative value which demonstrated the build-up of C-CO_2 emission at the intense fertilization system.

At the organic system of fertilization, the intensity of mineralization by the emission of C-CO_2 was 1.07–1.09 times lower by the average value and the median compared to the intense system of fertilization. The amplitude and normalized range of C-CO_2 emission were shifted towards lower absolute values. The coefficient of variation of C-CO_2 emission from the mineralization of by-products was 5 % lower and the coefficients of asymmetry and excess were positive and deviated insignificantly from the center of distribution, which demonstrated significant stabilization of the level of mineralization of by-products and C-CO_2 emission into the atmosphere.

The estimation of C-CO_2 emission from humus mineralization at the intense fertilization system was at the level of 12.2 t/ha both by the median and the average value. The amplitude range was 7.5 t/ha. By its value the median leaned towards the upper typical value, and the typed range of C-CO_2 emission from humus mineralization was 1.6 t/ha. The coefficient of variation was 20 % and the coefficients of asymmetry and excess of sampling distribution were positive with a considerable deviation of the distribution from the sampling center which demonstrated the enhanced humus mineralization.

At the organic fertilization system, the average and median emission of C-CO_2 from humus mineralization was 1.16–1.17 lower, and the absolute and typed range was 4.2 and 2.28 times more constricted compared to the intense system of fertilization. The variation coefficient of C-CO_2 decreased down to 5.4 %, and the asymmetry coefficient was negative and had a high absolute value which demonstrated the slowing down of emission processes for C-CO_2 for humus mineralization at the organic fertilization system.

The total emission of C-CO_2 from humus mineralization and by-products at the intense fertilization system both by the average and median values was 46.7 t/ha, and the amplitude and normalized range of changes in C-CO_2 emission almost coincided. The variation coefficient did not exceed 5 %, and the coefficient of asymmetry was in the range of the center of distribution which demonstrated stable high C-CO_2 emission from the processes of mineralization of humus and by-products at the intense fertilization system.

The total emission of C-CO_2 from the total mineralization decreased 1.07–1.08 times regarding the control fertilization system both by the average value and by the median which mostly leaned towards the minimal typical value (42.0 t/ha), which was 1.07 times lower compared to the control. The coefficient of variation of the total emission of C-CO_2 was 5 % lower and the coefficient of distribution asymmetry was positive and deviated a little from the center of parameter distribution which demonstrated the stabilization of the emission of C-CO_2 from the mineralization of humus and by-products at the lowest level.

The estimation demonstrated that at the intense system of fertilization, 2.86–2.93 t/ha of the mineralization of by-products were per 1 t of humus mineralization; at the low-cost fertilization system: 3.15–3.16 t/ha C-CO_2 of by-products were per 1 t from humus mineralization, and at the organic fertilization system: 1 to 3.14–3.15. In the percentage terms, at the intense fertilization system 75–77 % were due to the emission of C-CO_2 from the mineralization of by-products, and 23–25 % – C-CO_2 from humus mineralization; at the low-cost system: 75–76 % and 24–25 %; at the organic fertilization system: 76 % and 24 % respectively.

While passing to the organic system of fertilization there is an extension in the ratio of the emission of C-CO_2 due to the mineralization of by-products per one unit of C-CO_2 from humus mineralization at more or less stable ratio of mineralization items in the total emission of C-CO_2 regardless of the fertilization system.

The capacity of balance of carbon oxide (Cap.b$_{C\text{-}CO2}$) characterizes the value of its circulation, thus, the higher is the value of Cap.b.$_{C\text{-}CO2}$, the more intense is the circulation of substances and the intensity of crop rotations [15–16]. The capacity of C-CO_2 balance in the agrocenosis of a short crop rotation changes considerably at different systems of fertilization: at the intense system of fertilization the average and median values reached 92.0–93.0 t/ha, and the amplitude range changed from 86.0 t/ha to 98.0 t/ha. The typed interval Cap.b.$_{C\text{-}CO2}$ almost coincided with the amplitude range, and the value of Cap.b.$_{C\text{-}CO2}$ by the median leaned towards the minimal typical value (90.0 t/ha), which reflected on the value of the coefficient of parameter variation that did not exceed 5 %. The coefficients of asymmetry and excess of sampling had negative values and an insignificant deviation from the center of sampling distribution which demonstrated the stabilization of Cap.b.$_{C\text{-}CO2}$ at the mentioned level that corresponded to the intense system of fertilization.

At the organic fertilization system, the value of Cap.b.$_{C\text{-}CO2}$ decreased 1.10 times (85 t/ha) by the average value and the median. By the minimal value the amplitude range decreased by 7 t/ha (1.1 times less). The normalized typed range decreased by 6.5 t/ha by the minimal value, and by 8 t/ha – by the maximal typical value. The coefficient of variation Cap.b.$_{C\text{-}CO2}$ was at the level of 5–6 %, and the coefficients of asymmetry and excess had a positive value and an insignificant deviation from the center of sampling distribution, which demonstrated the stabilization of the value of Cap.b.$_{C\text{-}CO2}$ at the level, formed at the organic fertilization system, that may be deemed considerably different from the intense system of fertilization.

The balance of C-CO_2 in conditions of the intense system of fertilization was positive both by the average value (+0.46 t/ha), and by the median (+0.10 t/ha). The amplitude range of the balance fluctuated from –1.60 t/ha to +6.0 t/ha, and a typical interval range – from –1.00 t/ha to +0.30 t/ha. The value of C-CO_2 balance by the median leaned towards the upper typical value (+0.30 t/ha). The coefficient of balance variation was 554 % which demonstrated high instability and was proven by the coefficients of asymmetry and excess that had positive values with a considerable deviation from the distribution center.

In conditions of the organic system of fertilization, the average value of C-CO_2 balance was +0.75 t/ha, which was 1.63 times higher compared to the intense system of fertilization. The amplitude range fluctuated from –1.0 t/ha to +1.51 t/ha. The value of C-CO_2 balance by the median was +1.11 t/ha which was 18–19 times higher compared to the intense system of fertilization, *i.e.* the meaning mostly leaned to the upper typical value (+1.51 t/ha). The typed interval of the change in C-CO_2 balance altered in the positive interval of values. The coefficient of variation of C-CO_2 balance was 124 %, and the asymmetry coefficient acquired a negative value with a considerable deviation from the center of sampling distribution which demonstrated the stabilization of C-CO_2 balance.

In conditions of the intense system of fertilization, the intensity of C-CO_2 balance (Ib, %) was 101 % on average for a crop rotation, and the amplitude range changed from 96.5 % to 115 %, and by the median – 99 %. The amplitude and normalized range changed from 96.5–98.0 % to 101–115 %. The variation coefficient Ib, % (C-CO_2) was under 10 % and the asymmetry coefficient was positive and deviated considerably from the center of sampling distribution.

The intensity of balance of C-CO_2 at the organic fertilization system exceeded 100 % by the average and median values, similar to the amplitude and normalized range of the change in Ib (C-CO_2). The coefficient of variation Ib (C-CO_2) was at the level of 1.22 %, and the coefficients of asymmetry and excess of the sampling were negative and had an insignificant deviation from the center of the distribution which demonstrated slowing down of the circulation Ib (C-CO_2) in the agrocenosis of a short crop rotation in conditions of the organic system of fertilization which was a limiting factor in the process of forming the performance of a short crop rotation at the organic fertilization system.

The intensity of C-CO_2 balance at the organic fertilization system exceeded 100 % by the average and median values, similar to the amplitude and normalized range of the change in Ib (C-CO_2). The coefficient of variation Ib (C-CO_2) was at the level of 1.22 %, and the coefficients of asymmetry and excess of the sampling were negative and had an insignificant deviation from the center of the distribution which demonstrated slowing down of the circulation Ib (C-CO_2) in the agrocenosis of a short crop rotation in conditions of the organic system of fertilization which was a limiting factor in the process of forming the performance of short crop rotation at the organic fertilization system.

The general model of involving C-CO_2 in the formation of structural components of the total phytomass demonstrated a direct correlation of medium strength

Table 3. The equations of regression and coefficients of correlation coefficients between the level of sequestration of C-CO_2 into the components of total phytomass and the performance of a short crop rotation (general model)

Relation parameter	Regression equation	Coefficients:		Reliability R., p
		correlation, R	deter-mination R^2	
Main products, t/ha				
C-CO2 in the main products, t/ha	y = 1.32 + 1.15*x	0.81	0.66	0.00001
C-CO2 in by products, t/ha	y = 12.9 + 1.61*x	0.59	0.35	0.0041
C-CO2 of roots, t/ha	y = 14.5 + 0.58*x	0.65	0.43	0.0024
C-CO2 of total phytomass, t/ha	y = 27.6 + 3.56*x	0.73	0.54	0.0002
Capacity balance C-CO_2, t/ha	y = 59.3 + 6.45*x	0.76	0.58	0.0007
*Yield of f.u., t/ha				
C-CO2 in the main products, t/ha	y = 1.42 + 0.87*x	0.81	0.66	0.0001
C-CO2 in by products, t/ha	y = 13.3 + 1.19*x	0.58	0.35	0.0060
C-CO2 of roots, t/ha	y = 14.5 + 0.43*x	0.65	0.43	0.0031
C-CO2 of total phytomass, t/ha	y = 28.1 + 2.68*x	0.75	0.56	0.0002
Capacity balance C-CO_2, t/ha	y = 60.2 + 4.84*x	0.75	0.56	0.0001
Yield of digestible protein, t/ha				
C-CO2 in the main products, t/ha	y = 2.16 + 8.25*x	0.75	0.56	0.00008
C-CO2 in by products, t/ha	y = 13.9 + 12.1*x	0.58	0.35	0.006
C-CO2 of roots, t/ha	y = 15.0 + 3.84*x	0.55	0.31	0.0119
C-CO2 of total phytomass, t/ha	y = 30.0 + 25.9*x	0.69	0.48	0.0006
Capacity balance C-CO_2, t/ha	y = 63.8 + 46.5*x	0.71	0.5	0.0003

Note: * f.u.- feed units ,t/ha

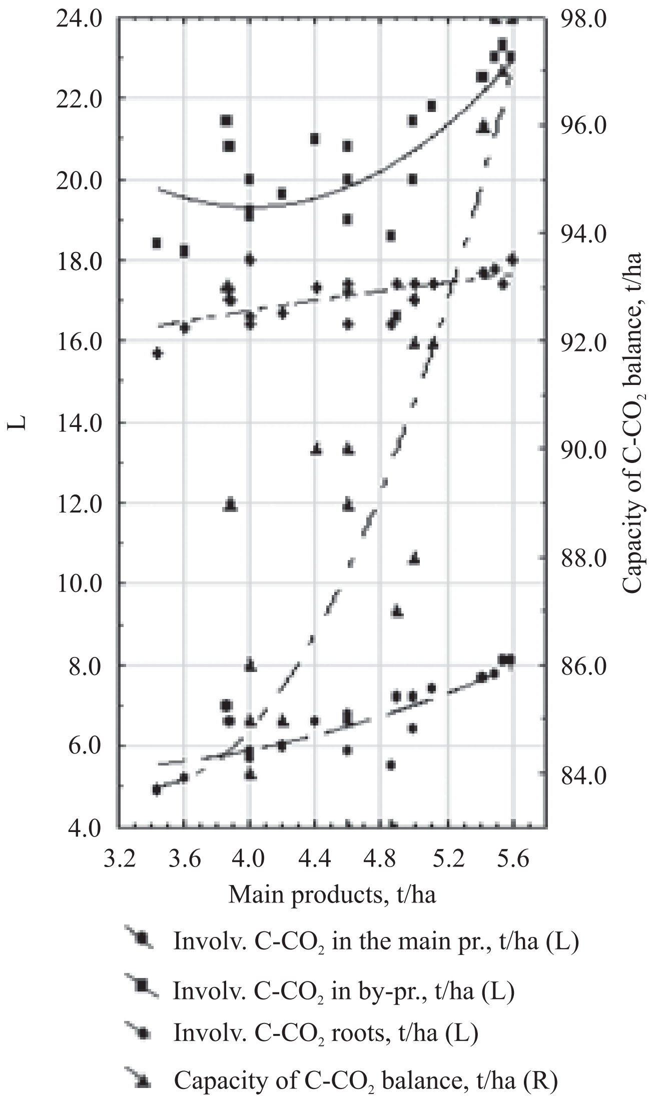

Fig. 1. The general model of the correlation between the yield of the main products, the capacity of C-CO_2 balance and the level of sequestration of C-CO_2 into the components of total phytomass of a short crop rotation

between these parameters. The correlation between the items of involving C-CO_2 of the main products, the total phytomass and the yield of the main products was at the level of R = 0.73–0.83 ± 0.02; R^2 = 0.53–0.69, and with the involvement of C-CO_2 in by-products and the root mass the relation was at the level of medium direct correlation: R=0.59–0.63 ± 0.02; R^2 = 0.35–0.40 (Table 3). There were 1.15 units of C-CO_2 per one unit of the yield of main products, 3.56 units of C-CO_2 for total phytomass, 1.61 units of C-CO_2 – for by-products, 0.58 units of C-CO_2 – for the roots.

A direct correlation was determined between the main products and the capacity of C-CO_2 was determined at the level of R = 0.76 ± 0.02; R^2 = 0.58, and 6.45 units of C-CO_2 were per one unit of the yield of main products.

At the intense fertilization system, there is enhanced direct correlation between the yield of the main products and the involvement of C-CO_2 in the formation of structural components of the total phytomass up to the values of R=0.86–0.88 ± 0.02; R^2 = 0.74–0.77. It was established that there was 1.26 times more involvement of C-CO_2 of the main and by-products, 1.46 times more C-CO_2 of the total phytomass per one unit of the yield of the main products prior to the formation of structural components of the total phytomass, and 56.3 units of the capacity of C-CO_2 balance per one unit of increasing the yield of the main products which is 1.05 times lower compared to the general model (Fig. 1).

A direct correlation dependence was preserved between the yield of the main products and the capacity balance at the level, the same for the intense system of fertilization (R = 0.88 ± 0.02), and there was 1.06–1.11 times less C-CO_2 per one unit of increasing the main products compared to the control fertilization system and the general model of relations for the parameter.

An intense circulation of C-CO_2 occurs between the atmosphere and agroecosystems due to the process of photosynthesis and breathing. A considerable part of C-CO_2, absorbed by agricultural crops, is spent for breathing processes and is returned to the atmosphere, and another part takes part in forming the aboveground and underground phytomass and dead organic matter.

The anthropogenic activity changes the intensity of C-CO_2 circulation in agroecosystems, a part of dead organic biomass is decomposed by microorganisms and is returned in the form of CO_2 into the atmosphere, while some part may be preserved as humus for some time. From this standpoint, the fertilization system is a determining factor of managing the circulation of C-CO_2 in agrocenoses of short crop rotations. The general model of C-CO_2 circulation demonstrated an established direct correlation between the yield of the main products and the involvement of CO_2 in the structural components of the total phytomass. There was strong direct correlation between the main products and the involvement of C-CO_2 of the main products and the total phytomass, whereas with the involvement of C-CO_2 in by-products and roots the relation was found at the level of medium direct correlation and with the capacity of C-CO_2 balance the level of the relation increases to the level of strong direct correlation.

There were 1.15 units of C-CO_2 per one unit of the yield of the main products, 1.61 units – for by-products, 0.58 units – for the root mass, 3.56 units of C-CO_2 – for the total phytomass. 6.45 units of the capacity balance were per one unit of the yield of the main products.

In conditions of the intense fertilization system, the level of correlation relationships between the yield of the main products and structural components was preserved at the level of high direct correlation relations: R = 0.75–0.88 ± 0.02; R^2 = 0.66–0.77. A higher share of C-CO_2 involvement was found per one unit of the yield of the main products: the main and by-products – 1.26-fold increase (1.45 and 2.03 units), root mass – 1.46-fold increase (0.85 units) and total phytomass (5.20 units), and the capacity of balance was spent 1.18–1.20 times more (7.6–7.8 units) compared to the general model of mutual relations.

At the organic fertilization system, the yield of the main products with the involvement of C-CO_2 into structural components of the total phytomass weakened to the medium level of inverse correlation (R=–0.43–0.48 ± 0.02; R^2 = 0.19–0.23), and between the yield of the main products and the capacity of C-CO_2 balance the relation was at the level of inverse correlation at the medium level: R = –0.49 ± 0.02; R^2 = 0.24. The relation between the yield of the main products and the involvement of C-CO_2 in the formation of the root mass was at the level of medium direct correlation which demonstrates the intensity of the formation of the root system at the organic fertilization system. The regression coefficients in the equations of dependence between the yield of the main products and structural components of the total phytomass were negative, which demonstrated the limitations of C-CO_2 involvement in the phytomass of the main products. For instance, the formation of one unit of the main products lacked 0.045 units of C-CO_2, that of by-products – 0.66 units, total phytomass – 0.90 units of C-CO_2, and the capacity of C-CO_2 balance in the deficiency was 1.10 units of C-CO_2.

The yield of feed units from 1 ha of the crop rotation in the general model of dependences between the involvement of C-CO_2 in the structural components of the total phytomass and the capacity balance had direct medium and strong correlation. With the involvement of C-CO_2 in the main products and to the total phytomass at the level of R = 0.75–0.81 ± 0.02; R^2 = 0.56–0.66, and with the involvement of C-CO_2 in the by-products and roots – at the level of direct medium correlation: R = 0.59–0.65 ± 0.02; R^2 = 0.35–0.42. The capacity of balance correlated with the yield of feed units per 1 ha of agricultural fields at the level of

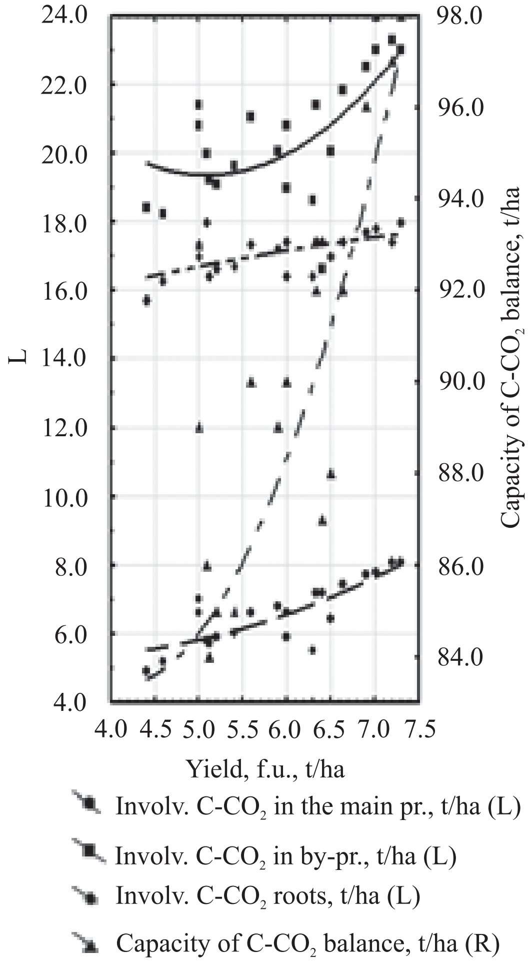

Fig. 2. The general model of the correlation between the yield of the f.u, the capacity of C-CO_2 balance and the level of sequestration of C-CO_2 into the components of total phytomass of a short crop rotation

strong direct correlation: R=0.75±0.03; R^2=0.56. There were 0.87 units of C-CO_2 of the main products, 1.19 units of by-products, 2.68 units of the total phytomass and 4.84 units of the capacity C-CO_2 balance per one unit of the yield of feed units.

At the intense fertilization system, the correlations with the yield of feed units from 1 ha of the crop rotation and the involvement of C-CO_2 in the components of the total biomass structure were preserved at the level of direct correlation, which corresponded to a high level of correlation: R = 0.86–0.88 ± 0.02; R^2 = 0.74–0.76, and the capacity of C-CO_2 balance correlated with the yield of f.u. at a higher correlation level (R = 0.86 ± 0.02; R^2 = 0.74) compared to the general model. There was 1.24–1.26 times more C-CO_2 of the main and by-products, 1.46 times more C-CO_2 in the total phytomass and 1.14 times more C-CO_2 of the capacity balance per one unit of the yield of f.u. (Fig. 2).

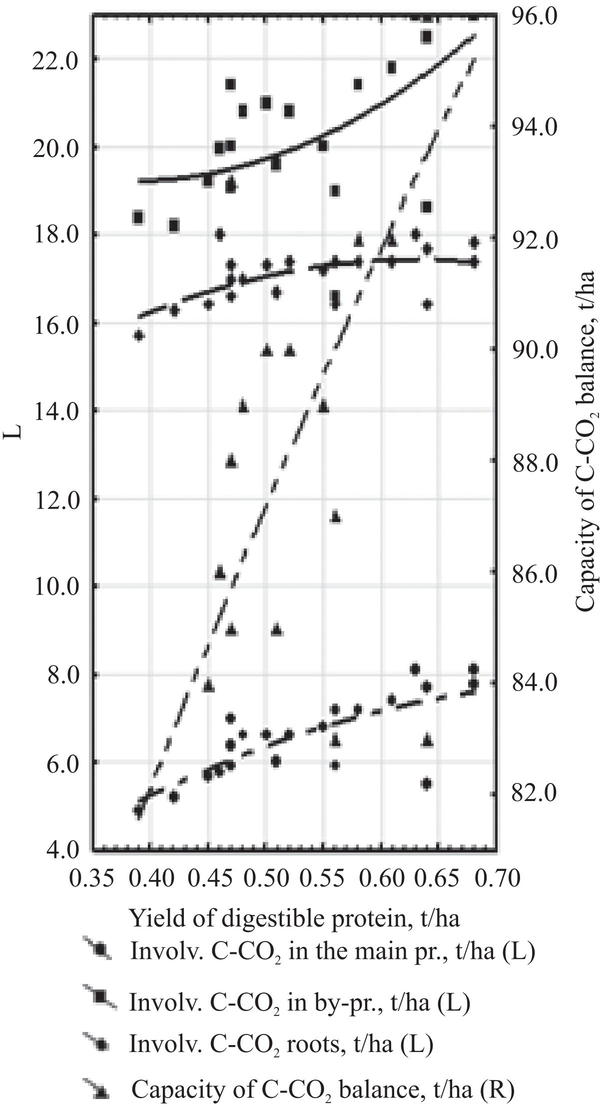

Fig. 3. The general model of the correlation between the yield of digestible protein, the capacity of C-CO_2 balance and the level of sequestration of C-CO_2 into the components of total phytomass of a short crop rotation

While applying the organic fertilization system, the correlations between the yield of f.u. and the involvement of C-CO_2 in the structural components of the total phytomass and the capacity balance acquired negative values, and with the involvement of C-CO_2 in the root system the relation was at the level of direct medium correlation which demonstrated enhancing the processes of root system formation.

The deficiency of involving C-CO_2 in the formation of structural components while forming the yield of f.u. from 1 ha of agricultural fields was –0.02 units of the main products, –0.047 units of by-products and –0.62 units of the total phytomass, and the deficiency of the balance capacity was –0.66 units of C-CO_2, which served as the main limiting factor of the increase in agrocenosis performance.

According to the general model of the yield of digestible protein per 1 ha of agricultural fields, direct correlation was established with the involvement of C-CO_2 in structural components of the total phytomass at the medium and strong level (Fig. 3).

Thus, the yield of digestible protein and involvement of C-CO_2 in the main products and the total phytomass had strong direct correlation: R = 0.69–0.75 ± 0.02; R^2 = 0.48–0.56, and with the involvement of C-CO_2 into by-products and roots the correlation was at the medium level: R = 0.55–0.56 ± 0.02; R^2 = 0.30–0.32, which was the weakening of correlations at the model of involvement in structural components of nitrogen phytomass. There were 8.25 units of C-CO_2 for the main products, 12.1 units of C-CO_2 for by-products, 3.84 units of C-CO_2 for the roots, 25.9 units of C-CO_2 for the general phytomass and 46.5 units of C-CO_2 for balance capacity per one unit of the yield of digestible protein. There was 1.15 times less C-CO_2 of the main products, 1.26 times less C-CO_2 – of by-products, 1.44 times more C-CO_2 – root mass and 1.33 times less C-CO_2 of the total phytomass per one unit of the yield of digestible protein, and 1.07–1.22 times less capacity balance of C-CO_2 was involved compared to the general model and the model of interrelations in the intense fertilization system.

In conditions of the organic fertilization system, the correlation relationships between the yield of digestible protein and the involvement of C-CO_2 into the structural components of the total phytomass and the balance capacity became of inverse character at the level of medium and weak correlation relationships: R = 0.38–43 ± 0.02; R^2 = 0.15–0.19, and with the involvement of C-CO_2 in the main products and the root system the correlation was direct at the medium level of values: R = 0.39–0.43 ± 0.03; R^2 = 0.15–0.19.

The deficiency of the balance capacity per one unit of the yield of digestible protein was 1.75 units of C-CO_2, total phytomass and by-products – –3.13 and –2.87 units of C-CO_2, and the involvement of C-CO_2 in the main products occurred with insignificant proficit: 0.18 and 0.83 units of C-CO_2.

It was established that the yield of the main products in the general model of performance of a short crop rotation had strong direct correlation with the removal of nitrogen with the main products (R = 0.86 ± ± 0.03; R^2 = 0.74), and with N from humus minerali-

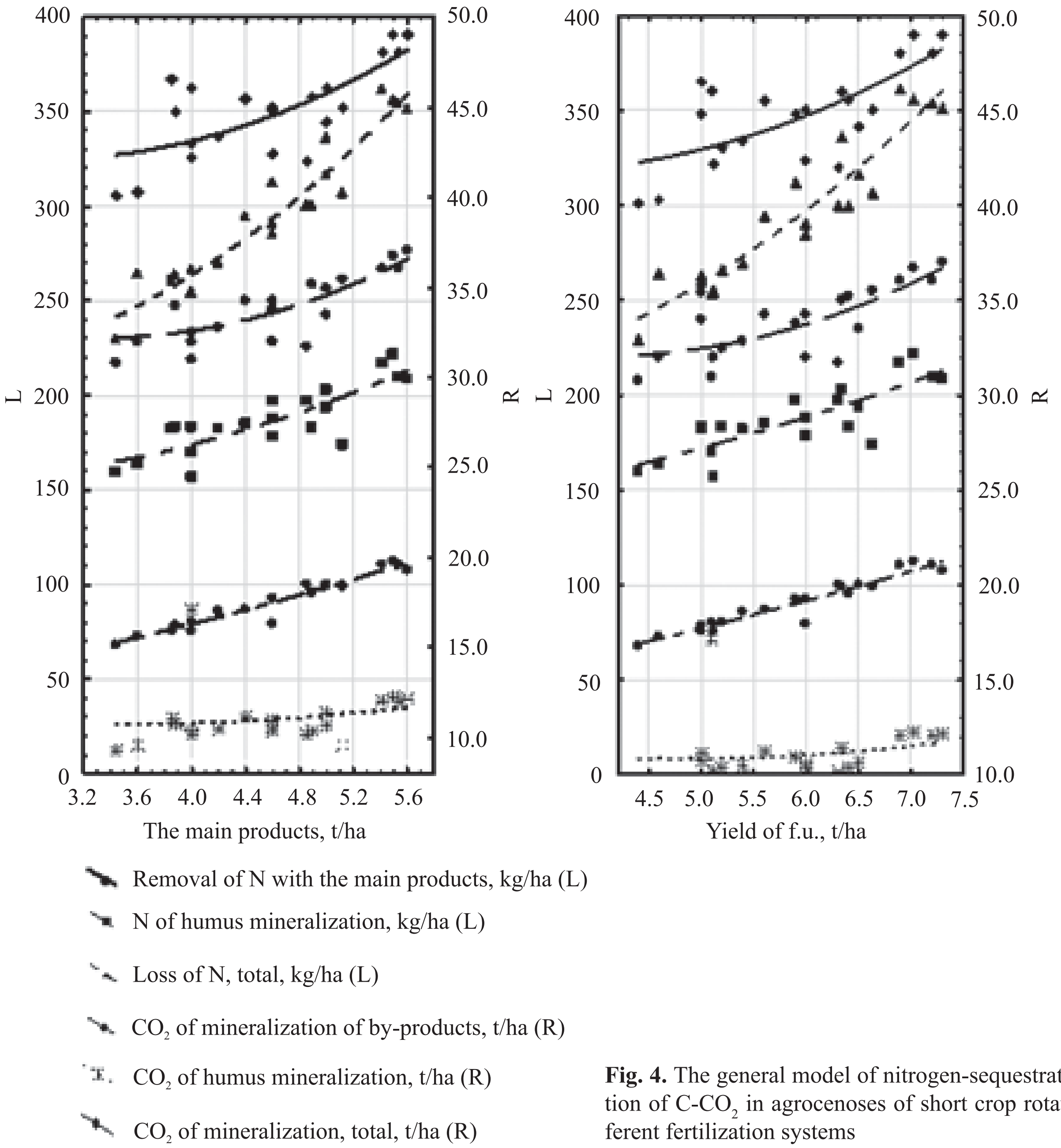

Fig. 4. The general model of nitrogen-sequestration circulation of C-CO_2 in agrocenoses of short crop rotations at different fertilization systems

zation R = 0.83 ± 0.02; R^2 = 0.69. The general loss of N correlated with the yield of the main products at the level of strong direct correlation: R = 0.85 ± 0.02; R^2 = 0.73. A direct correlation relationship was established between the yield of the main products and C-CO_2 from mineralization of by-products (R = = 0.74 ± 0.02; R^2 = 0.55), and with C-CO_2 from humus mineralization the correlation relationship was at the low level: R = 0.25 ± 0.09; R^2 = 0.06 (Fig. 3).

The presence of direct correlation relationships between the general removal of N, nitrogen from humus mineralization, the total loss of N and C-CO_2 of mineralization of by-products and C-CO_2 of the general mineralization demonstrated the relevance of nitrogen-carbon circulation with the formation of crop rotation performance via the yield of the main products. According to the established regularity, the combination of direct correlation relationships is formed by the yield of feed units from 1 ha of agricultural fields. The correlation relationships between the items of nitrogen-carbon balance were at the level of R = = 0.81–0.85 ± 0.02; R^2 = 0.66–0.73 regarding nitrogen and R = 0.71–0.74 ± 0.02; R^2 = 0.50–0.55 regarding C-CO_2 (Fig. 4).

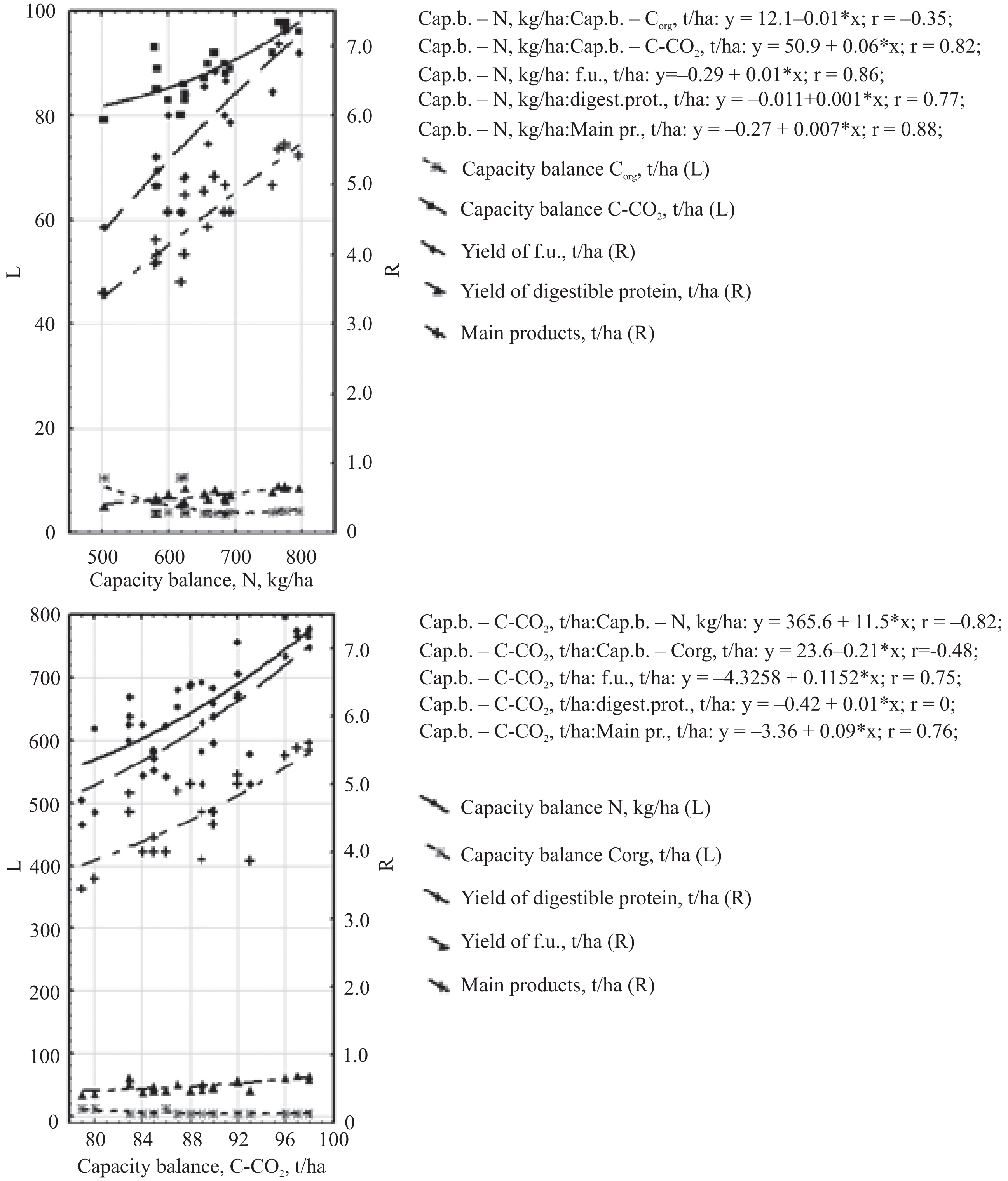

Fig. 5. The general model of the dependence between the balance capacity of N, C_{org} and C-CO_2 and the performance of short rotations

At the intense fertilization system, the correlation relationship between the yield of the main products, the total removal of nitrogen, the nitrogen of humus mineralization and the general loss of N was at the level of strong direct correlation: R = 0.81–0.85 ± 0.02; R^2 = 0.65–0.72, and with N of denitrification the relation was inverse at the level of medium correlation: R = –0.58 ± 0.03; R^2 = 0.35. The yield of the main products with C-CO_2 of the mineralization of by-products correlated at the level of strong direct correlation and with C-CO_2 of mineralization the relation was inverse and at the medium level: R = –0.56 ± 0.02; R^2 = 0.32. In general, C-CO_2 of total mineralization with the yield of the main products correlated at the level of R = 0.68–0.70 ± 0.02; R^2 = 0.46–0.50. The relations between the yield of feed units from 1 ha of agricultural fields and the components of nitrogen-carbon balance were formed by a similar regularity: the correlation relationship with the total removal of N, the nitrogen of humus mineralization, the general loss of N was at the level of strong direct correlation: R = = 0.77–0.81 ± 0.02; R^2 =0.59–0.66; R^2 = 0.35–0.45, and with the loss of nitrogen via denitrification the correlation was inverse and at the medium level: R = –0.59 ± ± 0.03; R^2 = 0.35. There was direct relationship between the yield of feed units and C-CO_2 of the mineralization of by-products and C-CO_2 of general mineralization: R = 0.70–0.87 ± 0.02; R^2 = 0.49–0.75, and C-CO_2 from humus mineralization the relationship was at the level of inverse correlation of the medium level: R = –0.58 ± ± 0.02; R^2 = 0.35.

There was 1.24 times more nitrogen of the main products, 1.22 times more N of humus mineralization and 1.18 times more expenses of the general removal of nitrogen, 1.54 times more C-CO_2 from the mineralization of by-products regarding the general model of relationships per one unit of the yield of the main products.

There was 1.16 times less total N in the main products per one unit of the yield of the main products, 1.12 times less N from humus mineralization and 1.33 times less N of the total loss from mineralization regarding the intense system of fertilization. 1.4 times less C-CO_2 was spent per one unit of the formed main products and 2.07 times less C-CO_2 from mineralization in general.

A high tense correlation relationship was established between the yield of the main products and nitrogen in the main products, nitrogen of humus mineralization and the total loss of nitrogen for mineralization at the organic fertilization system: R = 0.85–0.88 ± 0.02; R^2 = 0.72–0.77, and with C-CO_2 from mineralization of by-products, humus mineralization and general mineralization the relationship was at the level of weak correlation, which demonstrated the disbalance in nitrogen-carbon circulation, when due to enhanced humification there was a weaker uptake of CO_2 from mineralization, which limited the intensity of photosynthesis and impacted the decrease in the performance of crops in the agrocenosis of a crop rotation. The relation between the yield of feed units from 1 ha of agricultural fields and the components of balance between N and C-CO_2 from mineralization was formed by a similar regularity: R = 0.86–0.88 ± 0.02; R^2 = 0.74–0.77 for the items of nitrogen and weak correlation for items of C-CO_2 from humus mineralization and by-products.

1.1 times less nitrogen was spent per one unit of the yield of the main products, 1.32 times less nitrogen from humus mineralization and 1.50 times less nitrogen from general mineralization in the agrocenosis compared to the intense system of fertilization, and the loss of C-CO_2 by items of balance was deficient: regression coefficients were negative which demonstrated the disbalance of nitrogen-carbon circulation in the agrocenosis of a crop rotation at the organic fertilization system.

The factor analysis demonstrated that the determining factors of nitrogen-carbon circulation were as follows: the weight of total phytomass (performance), nitrogen in the total phytomass, balance capacity of nitrogen, C_{org}, C-CO_2. The correlation regarding the main factor was high and inverse. It was established that there was constricted correlation relationship between the balance capacity of N and balance capacity of C-CO_2 (R^2 = 0.82 ± 0.03; R^2 = 0.67), and with the balance capacity C_{org} the relationship was at the level of weak inverse correlation (R = –0.40 ± 0.03; R^2 = 0.16). A similar level of relationship was established between the balance capacity of C-CO_2 and C_{org}: R = –0.50 ± 0.02; R^2 = 0.25, but there was strong correlation between the balance capacity of N and C-CO_2 and the yield of the main products: R = 0.76–0.88 ± 0.03; R^2 = 0.58–0.78, and with the capacity of $C_{org}$the relationship was inverse at the level of medium correlation: R = = 0.35–0.45 ± 0.02; R^2 = 0.12–0.21 (Fig. 5).

CONCLUSIONS

The performance of short crop rotations is determined by the capacity of nitrogen and C-CO_2 balance. Strong inverse correlation was found between the capacity of N and the ratio between C and N in the agrocenosis, which demonstrated that enhancing the humification processes (ratio constriction) led to the increase in the capacity of C_{org} balance and the decrease in the capacity level of C-CO_2 balance (enhancing mineralization), related to the reduction in the performance of crops in the agrocenosis of a crop rotation at the organic system of fertilization.

The correlation level between the balance capacity of C-CO_2 and $C_{орг}$ is medium and inverse, and with the yield of the main products, feed units and digestible protein – at the level of strong direct correlation. The performance of short crop rotations is determined by the capacity of C-CO_2 balance.

General mineralization of by-products and humus in the agrocenosis and humification processes are antagonists, so extending the ratio between C and N at the intense fertilization system stimulates the increase in performance and reducing C to N at the organic fertilization system enhances the humification process due to binding of C_{org} into humus and limits mineralization which leads to the reduction in agrocenosis performance.

Секвестрація оксидів карбону за різних систем удобрення в агроценозах

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Мета. Розробити методологію агроекологічної оцінки продуктивності короткоротаційної сівозміни за умов інтенсивної та органічної систем удобрення на основі встановлення нормативних параметрів емісії і секвестрації обігу C-CO_2 при використанні побічної продукції у якості органічних добрив в умовах сучасної кліматичної системи Лісостепу України. **Методи.** Польовий, статистичний, лабораторний. **Результати**. Продуктивність короткоротаційних сівозмін визначається ємністю балансу C-CO_2. Між ємністю N та співвідношенням C до N в агроценозі виявлено обернену сильну кореляцію, а це свідчить про те, що при посиленні процесів гуміфікації (звуження співвідношення) відбувається зростання ємності балансу $C_{орг}$ і зниження рівня ємності балансу C-CO_2 (посилення мінералізації) і пов’язано з зниженням продуктивності культур в агроценозі сівозміни як за органічної системи удобрення. Між ємністю балансу C-CO_2 і $C_{орг}$ рівень кореляції середній і оберненого спрямування, а з виходом основної продукції, к. о. і перетравним протеїном на рівні прямої сильної кореляції. Висновки. Загальна мінералізація побічної продукції і гумусу в агроценозі та процеси гуміфікації є антагоністами, а тому розширення співвідношення C до N за інтенсивної системи удоб-рення стимулює ріст продуктивності, а звуження C до N як за органічної системи удобрення посилює процес гуміфікації за рахунок зв’язування $C_{орг}$ у гумус і стримує мінералізацію, що призводить до зниження продуктивності агроценозу за органічної системи удобрення.

Ключові слова: секвестрація, оксид карбону, органічна система удобрення, ємність балансу, основна продукція, перетравний протеїн.

Секвестрация оксидов карбона при разных системах удобрения в агроценозах

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Цель. Разработать методологию агроэкологической оценки производительности короткоротацийний севооборота в условиях интенсивной и органической систем удобрения на основе установления нормативных параметров эмиссии и секвестрации обращения C-CO2 при использовании побочной продукции в качестве органических удобрений в условиях современной климатической системы Лесостепи Украины. **Методы.** Полевой, статистический, лабораторный. **Результаты.** Производительность короткоротационных севооборотов определяется емкостью баланса C-CO_2. Между емкостью баланса N и соотношением C к N в агроценозах установлена обратная сильная корреляция, а это свидетельствует о том, что при усилении процессов гумификации (сужение соотношения) происходит рост емкости баланса $C_{орг}$ и снижение уровня емкости баланса C-CO_2 (усиление минерализации) и связано со снижением продуктивности культур в агроценозах севооборотов как при органической системе удобрения. Между емкостью баланса C-CO_2 и $C_{орг}$ уровень корреляции средний и обратного направления, а с выходом основной продукции, к. о. и перевариваемого протеина на уровне прямой сильной корреляции. **Выводы.** Общая минерализация побочной продукции и гумуса в агроценозах и процессы гумификации являются антагонистами, поэтому расширение соотношения C к N при интенсивной системе удобрения стимулирует рост производительности, а сужение C к N как при органической системе удобрения усиливает процесс гумификации за счет связывания $C_{орг}$ в гумус и сдерживает минерализацию, что приводит к снижению производительности агроценоза как при органической системе удобрения.

Ключевые слова: секвестрация, оксид углерода, органическая система удобрения, емкость баланса, основная продукция, перевариваемый протеин.

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